January 8, 1979
Q. Kerns/J. McCarthy

ENERGY DOUBLER ABORT KICKER

I. INTRODUCTION

Report UPC No. 20, "Energy Doubler Beam Abort System" describes two abort schemes: Abort Geometry I and Abort Geometry II. Here we discuss the kickers required for these two geometries. Table I below is from the report.

Table I - Kicker Requirements

Abort Geometry I		Abort Geometry II	
Kicker	MKV	Kicker	MKV 1
$\Delta\theta$	0.18mRad	$\Delta\theta$	0.36mRad
Length	8.3 m	Length	6 m
Field	0.84 kG	Field	2 kG
Aperture-HxV	5x4 cm	Aperture-HxV	5x3 cm
Rise Time	0.4μsec	Rise Time	1.6μsec
		Kicker	MKV 2
		$\Delta\theta$	0.94 ± .05
		Length	15.6 m
		Field	2 kG
		Aperture-HxV	5x4 cm
		Rise Time	1.6μsec

In this report, we shall consider a Ferrite Kicker for Abort Geometry I and a Silicon Steel Kicker for Abort Geometry II. Table II compares some properties of Ferrite and Silicon Steel (= transformer iron).

Table II - Ferrite vs. Steel

Property	Symbol	Ferrite	Si Steel
Initial perm.	μ_i	200-2000	500
Resistivity	ρ	$10^2 - 10^6$ ohm cm	60×10^{-6}
Dielectric Constant	K	15	1
Saturation B	B_s	4.5 kG	20 kG

One use of the above data concerns the longitudinal coupling impedance of the kicker to the beam. At high beam intensities the coupling impedance if too large can lead to beam instabilities and ferrite overheating due to I^2R losses from the current of the bunched beam. Low impedance is preferable.

Silicon steel in the magnetic circuit of the kicker lowers the coupling impedance compared to ferrite. At 53 MHz, for example, the steel has a skin depth of 2.4×10^{-4} cm and a resistance/square of 0.25 ohms. In contrast, ferrite may have centimeters of skin depth and resistances of > 100 ohms/square, plus the unwanted possibility of dimensional resonances.*

II. KICKER FOR ABORT GEOMETRY I

In this section we discuss a ferrite kicker. Figure 1 shows a cross-section of the magnet and Figure 2 the power supply system schematic.

The time between the 13th and first Booster batch is

$$\frac{84}{4} \times \frac{1}{53.104 \text{ MHz}} = 395 \text{ ns}.$$

*Dimensional resonances = rf standing waves in the ferrite. Appreciable rf energy may propagate into the ferrite because its $\rho >> 1/\omega K K_o$ whereas for steel $\rho << \frac{1}{\omega K K_o}$ and dimensional resonances cannot occur.

If the abort kicker tolerance is set such that a kick of .17 to .2 mr will suffice, then a kick set to produce .2 mr must reach .17 mr in 395 ns. This condition results in a magnet-load time constant of $\frac{.17}{.2} = 1 - e^{-t/\tau}$

$$\tau = \frac{-t}{\ell n\ .15} \qquad t = 395 \text{ ns}$$

$$\tau = 208 \text{ ns.}$$

Using a square gap the inductance per meter

$$L_m = 4\pi x 10^{-7} \text{ Hy/meter.}$$

For a 12.5 ohm system the maximum length of a module is equal to

$$\ell = \frac{2\tau R}{L_m} = 4.16 \text{ meters.}$$

The inductance L = 5.23 x 10^{-6} Hy. The current I for a 2 inch gap and 841 gauss is

$$I = \frac{B\ell}{\mu_o} = 3400 \text{ Amps.}$$

$B\ell$ = 3.5 kG-m = .105 milliradian @ 1 TeV. Two such units will suffice for a kick of .2 mr.

Because the peak field is well below the B_s for ferrite and because a 208 ns τ is required, ferrite is the material of choice. If a wire transmission test shows a longitudinal coupling impedance problem, damping will have to be added.

III. KICKERS FOR ABORT GEOMETRY II

For this case we choose a module 3 meters long to satisfy MKV 1 (using 2 modules) and MKV 2 (using 5 modules).

Figure 3 is a cross-section of the 2 kG kicker. Here the rise time is four times slower and we choose silicon steel in a 1 mil tape wound core configuration with a 7.5 cm gap.

The required current is

$$I = \frac{B\ell}{\mu_o} = 12 \text{ K amps.}$$

The inductance of a 3 meter module is (for a 377Ω line)

$$L = Zo\tau = 377 \times 10 = 3.77\mu\text{Hy}.$$

The required time constant of 832 ns can be obtained with a load resistor

$$R = \frac{L}{2\tau} = \frac{3.77 \times 10^{-6}}{1.664 \times 10^{-6}} = 2.27\Omega$$

The connecting cables from pulse line to kicker are 22 RG220's in parallel. The pulse line voltage V = 2IR = 54.5 KV. A single pulse line of characteristic impedance Zo = 0.324Ω could drive all seven modules simultaneously. For the switch, a low-inductance, multiple spark-gap may be more cost effective than switch tubes to handle the 84 K amps.

IV. KICKER COMPARISON

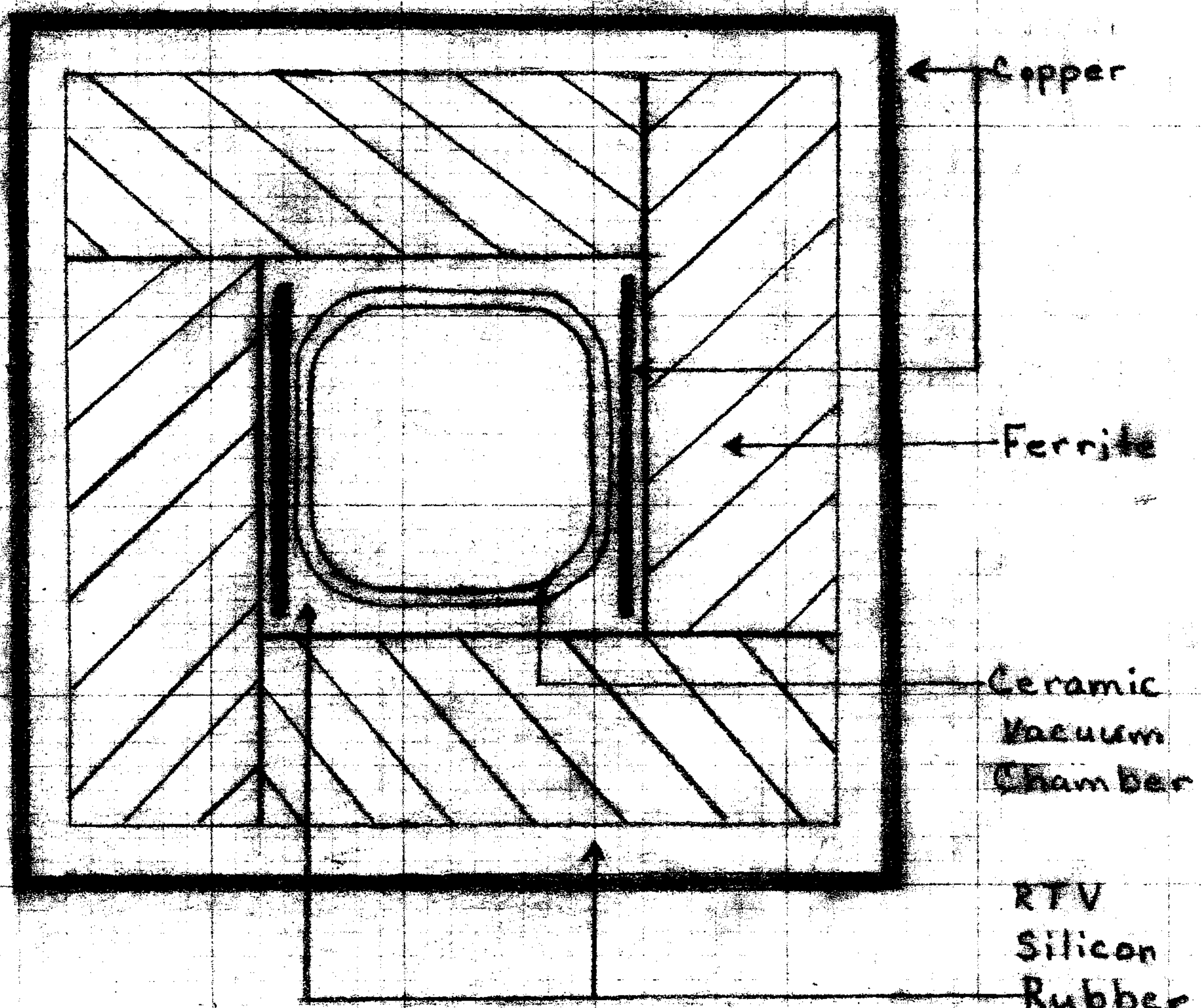
Item	Abort Geometry I	Abort Geometry II
Total $B\ell$	7 kG-m	43 kG-m
Number modules	2	7
Module current	3.4 K amps	12 K amps
Module Inductance	5.23μHy	3.77μHy
Terminating Resistor	12.5 ohms	2.27 ohms
Module Energy $\frac{1}{2}LI^2$	30 Joules	271 Joules
Average Power in a Termination @ 1 pulse/20 sec	150 Watts	343 Watts
Total Energy Stored in Pulse Lines	6 KJoules	48 KJoules
Peak Power per Module	145 MW	327 MW

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
-5-			

SUBJECT: Abort Kicker Magnet Cross Section
Figure 1

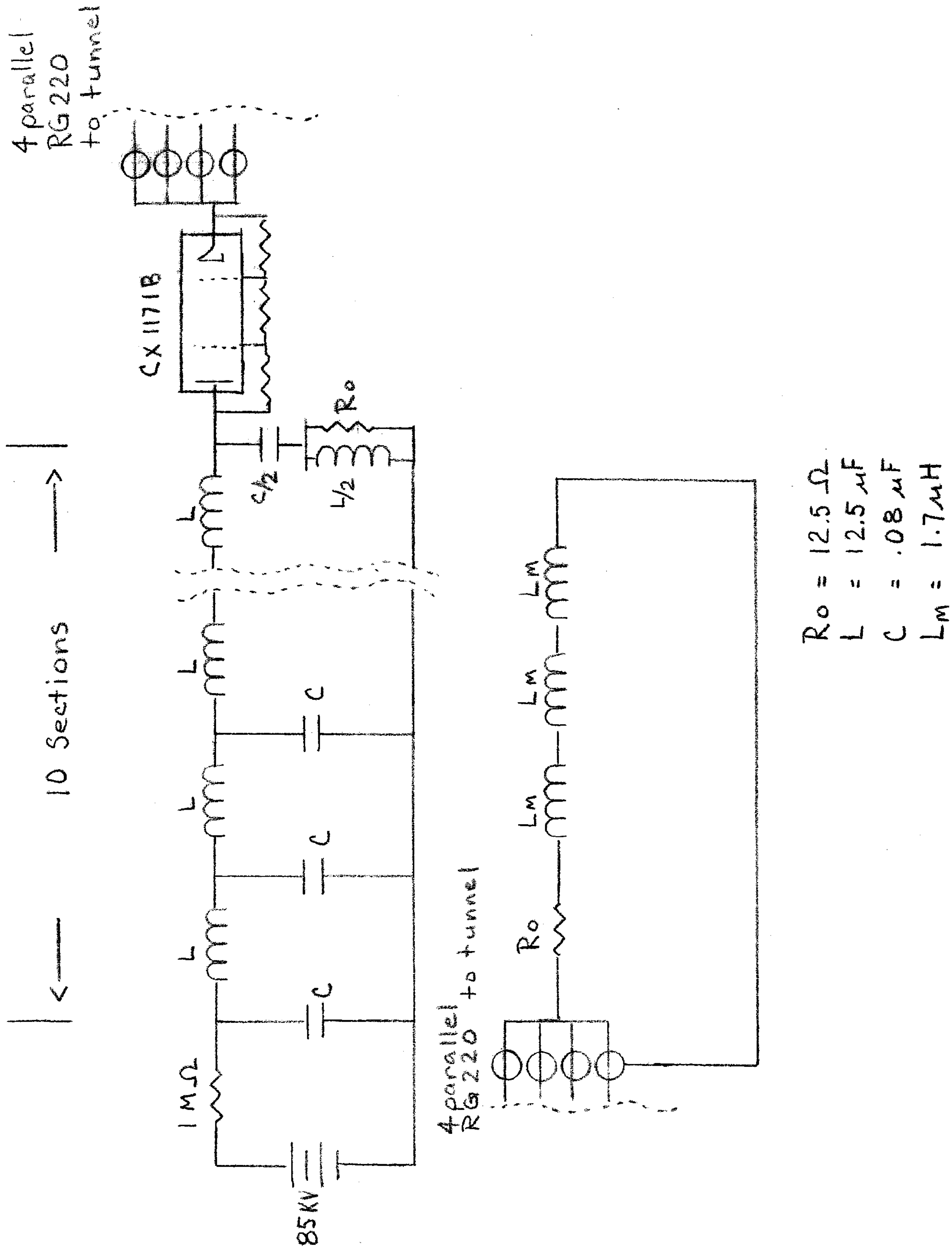
NAME	
DATE	REVISION DATE



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
-6-			

SUBJECT	NAME	DATE	REVISION DATE
Abort Kicker Power Supply Figure 2			



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
-7-			

SUBJECT	NAME	DATE	REVISION DATE
2 KG KICKER MAGNET MODULE	Q. A. KERNS	1-6-79	

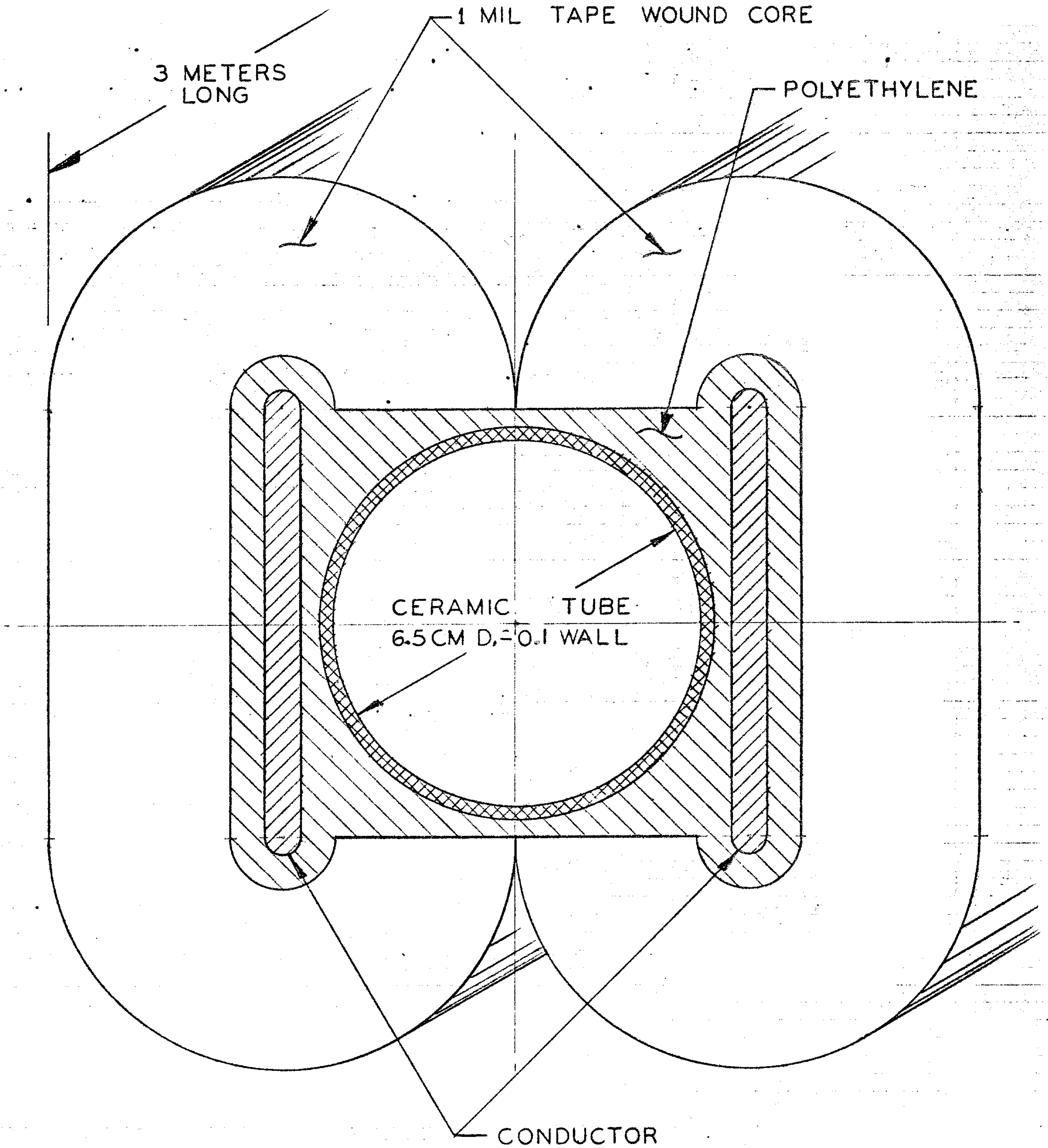


FIG-3 2 KG KICKER MAGNET